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INtrinsic Capacity and its RElAtionship With Life-SpacE Mobility (INCREASE): a cross-sectional study of community-dwelling older adults in Singapore

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ABSTRACT

Objectives To examine the association of intrinsic capacity (IC) with life-space mobility (LSM) among community-dwelling older adults and to determine whether age and gender modify this relationship.

Design Cross-sectional study.

Setting Public housing blocks, senior activity centres and community centres in the Northeastern region of Singapore.

Participants 751 community-dwelling older adults aged ≥55 years old and able to ambulate independently with or without walking aid.

Primary and secondary outcome measures IC and LSM. Standardised IC factor scores were calculated through confirmatory factor analysis using variables representing the five IC domains cognition, locomotion, sensory, vitality and psychological. LSM was measured using the University of Alabama at Birmingham Study of Aging Life-Space Assessment instrument. Association of IC with LSM and its effect modification by age and gender were examined with regression analyses.

Results The participants had a mean age of 67.6 and mean LSM score of 88.6. IC showed a positive and significant association with LSM (β=6.33; 95% CI=4.94 to 7.72) and the effect remained significant even after controlling for potential confounders (β=4.76; 95% CI=3.22 to 6.29), with p<0.001 for both. Age and gender did not demonstrate significant modification on this relationship.

Conclusions Our findings support the empirical rigour of the International Classification of Functioning, Disability and Health framework, which suggests that IC influences the extent to which a person participates in the community. Our findings also provide guidance for healthcare providers who aim to enhance LSM and promote healthy ageing in older adults.

Strengths and limitations of this study

- ► Multiple linear regression controlling for various confounders including demographic, economic and social factors was used to demonstrate independent association of intrinsic capacity (IC) with life-space mobility (LSM).
- ► IC factor scores for each participant were calculated from a number of self-reported and observed variables using structural equation modelling and used in our analyses.
- ► The cross-sectional design of the study limits the determination of causality and directionality in the relationship of IC and LSM.
- ► The study sample consisted of relatively high functioning older adults with high Activities of Daily Living (ADL) and Instrumental ADL scores, which limits generalisability of our findings to other populations.

INTRODUCTION

As population ageing becomes increasingly prevalent worldwide, many countries are witnessing an epidemiological transition characterised by the rising burden of chronic and degenerative diseases.[1] In addition to the need for long-term healthcare, older adults also face health-related problems such as malnutrition, depression and isolation.[2 3] Unfortunately, current healthcare systems are designed largely to provide fragmented and episodic short-term care, which may not adequately address the complex health needs of older adults.[4] Hence, there is a need to work towards a more person-centred model of care that follows older adults through their life course and that addresses not just their biological, but also their psychological and social needs.[5 6]

To facilitate this paradigm shift, WHO proposed a new conceptual model for 'Healthy ageing' in 2015, in which healthy ageing is defined as 'the process of developing and maintaining the functional ability that enables well-being in older age'.[4] As part of this model, intrinsic capacity (IC), defined as 'the composite of all physical and mental capacities of the person', was introduced as a multidimensional indicator that can be used as a measure of health in older people over time.[4]

IC is conceptualised as having five domains, namely cognition, locomotion, sensory, vitality and psychological.[7] It has been shown to be reliably estimated from a range of frequently collected biomarkers and self-reported measures representing these five domains.[8 9] IC declines have been shown to predict disease manifestations and decrements in Activities of Daily Living (ADL) and Instrumental ADL (IADL).[8 10] As such, IC levels of older adults can be tracked over time to allow early identification of abnormal deviations and timely interventions to prevent deterioration.[7 10] Furthermore, compared with crude risk assessment measures like chronological age, IC provides valuable information about one's physiological reserves, which can help guide healthcare providers in identifying the populations to target for interventions.[11 12] The multi-domain nature of IC also encourages integration of services and formulation of multi-pronged, multidisciplinary strategies, which are likely to be more effective in addressing the complex needs of older adults.[10 12] Moreover, unlike many traditional measures of health, IC carries a positive connotation by focusing on the preserved capacities of an individual, rather than their deficits and limitations.[7]

Taken together, IC can potentially be adopted in clinical practice as a useful tool to monitor and assess older adults' functional health status over time. At present, IC is still largely a theoretical construct as there is lack of a standardised metric and guidelines for its operationalisation in clinical and research settings.[7 9] There have been few empirical studies elucidating the association and predictive value of IC with ADLs, IADLs and adverse health events including falls, hospitalisation and mortality in older adults.[8 13–15] However, according to the 2001 International Classification of Functioning, Disability and Health (ICF) framework (see online supplemental figure 1), apart from activities (measured by ADLs and IADLs), participation, defined as one's involvement in a life situation and engagement in the community, is another important aspect of functioning.[16] Based on the framework, one's body functions (or IC) influences an individual's ability to be and to do what they have reason to value, which directly affects the extent to which they participate in the community.[4 7 16] The effect of IC on participation is in turn modified by contextual factors (environment and personal) and health conditions. However, the association between IC and participation is yet to be established empirically.

An individual's participation in the community can in turn be measured by his/her life-space mobility (LSM), which refers to the ability to move or travel in one's daily life, taking into account the frequency of movement and degree of independence.[17 18] Constricted LSM has been shown to be associated with negative outcomes such as increased risk of Alzheimer's disease and cognitive decline, frailty, decreased quality of life and even mortality.[19–22] While many studies have demonstrated the effect of environmental barriers like poor street conditions on LSM in older adults, the association between IC and participation is much less established.[23 24] Elucidation of this association would provide valuable information for healthcare providers when designing interventions that promote healthy ageing.

Aims and hypotheses

Using data from an ongoing community-based study, the Individual Physical Proficiency Test for Seniors (IPPT-S), we aim to: (1) examine the association of IC and the five domains with LSM and (2) investigate if age and gender modify the relationship between IC and LSM in community-dwelling older adults in Singapore. We hypothesise that IC is positively associated with LSM, as suggested by the ICF framework. We also hypothesise that increasing age and male gender attenuate the effect of IC on LSM, since older age has been associated with increased fear of falling and decreased confidence leading to restriction in community participation, while male older adults have been shown to participate less in community activities and have smaller social networks than their female counterparts.[25–28]

MATERIALS AND METHODS

Study description

The IPPT-S is an ongoing community-based frailty screening programme that aims to promote fitness and prevent or delay frailty progression in older adults.[29] Data from June 2018 to October 2019 were used for analysis in this study. Community-dwelling older adults residing in the Northeastern region of Singapore were invited through senior activity centres and resident committees. Inclusion criteria for participants include (1) age ≥55 years old, (2) community-dwelling, and (3) ability to ambulate independently (with or without walking aid). Individuals who live in residential care facilities were excluded. The assessment consisted of two components, a multidomain questionnaire and the short physical performance battery (SPPB).[29 30]

Patient and public involvement

No patients or members of the public were involved in the development of the research question, study design or interpretation of the data.

Measures of IC

Variables representing the five domains of IC, namely cognition, locomotion, sensory, vitality and psychological were included in the measurement of IC. All data had been collected by trained members of the study team, including research assistants, physiotherapists and nutritionist.

Measures of locomotion domain

SPPB Total Score

The SPPB consists of three tests (balance, chair stand and gait speed).[29] Tests of static balance included side-by-side, semitandem and full-tandem standing and time taken to remain in position was measured. For chair stand, time taken to complete five chair stands was recorded.

Gait speed was measured by duration of walking 10 m at normal pace.

Timed up and go

Timed up and go (TUG) is a test for dynamic balance and functional mobility.[31] Time taken to rise from a chair, walk 3 m, go round a cone and return to the seat was recorded.

5 times sit-to-stand

5 times sit-to-stand (5TSTS) measures lower body strength.[32] Participants stood from a sitting position as fast as they could with arms folded across their chest, and time taken to complete five repeats were measured.

Measures of psychological domain

Geriatric Depression Scale

The 15-item Geriatric Depression Scale (GDS) consists of yes/no questions pertaining to depressive symptoms and a score of ≥5 indicates depression.[33]

EuroQol-5 Dimensions (EQ-5D) anxiety/depression

Participants were scored from 0 to 4 based on the severity of anxiety/depression they felt, with 0 being 'none' and 4 being 'extreme'.[34]

Measures of cognition domain

Cognitive

The Chinese Mini Mental State Examination (CMMSE)[35] consists of 18 items and measures three kinds of cognitive functions: (1) Memory-measured by delayed word recall test, (2) Orientation-measured by summating the scores on eight items that test participants' orientation to time and place, and (3) Executive function-measured by summating the scores on five tasks: repeat the following phrase, three-stage command, say a sentence, read and obey what is written on the paper and copy this drawing.

Measures of sensory domain

Sensory

Sensory functions were assessed by self-reported absence or presence of hearing and/or visual impairments.

Measures of vitality domain

Exhaustion

Participants rated how frequently the statement 'I felt that everything I did was an effort' applied to them over the past week on a 4-point Likert scale, with 0 being 'Rarely or none of the time (less than 1 day)' to 3 being 'Most or all of the time (5–7 days)'.[36]

Mini Nutritional Assessment-Short Form

The Mini Nutritional Assessment-Short Form (MNA-SF) identifies geriatric patients who are malnourished or at risk of malnutrition.[37] It also screens for dementia, depression, mobility, acute disease and psychological stress. A score of <8 suggests malnutrition, 8–11 suggests risk of malnutrition, while 12–14 suggests normal nutritional status.

Grip strength

Grip strength was measured with a JAMAR Plus Hand Dynamometer (Sammons Preston, Bolingbrook, Illinois, USA).[38] Two trials were conducted for each hand and the higher reading was used for analysis.

LSM as a measure of participation

LSM was measured using the University of Alabama at Birmingham Study of Aging Life-Space Assessment (UAB-LSA) instrument.[18] The UAB-LSA defines five life-space levels: (1) rooms of your home other than the bedroom, (2) an area outside your home such as your porch, deck or patio, hallway (of an apartment building) or garage, in your own yard or driveway, (3) places in the neighbourhood, (4) places outside of your neighbourhood, but within your town and (5) places outside your town. For each life-space level, participants reported their frequency of attainment and degree of dependence. The frequency of attainment was scored from 0 (never) to 4 (daily), while the degree of dependence was scored 1, 1.5 or 2 representing 'personal assistance required', 'walking device required' and 'independent', respectively. A final composite score that ranges from 0 (completely homebound) to 120 (maximum mobility) was calculated. The minimum LSM score needed to be considered high participation is 60, since a person must fulfil at least life-space levels 1 and 2 to attain this score.[39]

Other measures included in the study

In addition to demographic information (age, gender, ethnicity), participants were asked a number of questions regarding social determinants, including socioeconomic status (highest educational level, housing type, employment status), lifestyle (smoking, alcohol) and social support and network.[29] Frailty, functional status and chronic medical conditions were also included as descriptive measures of the study sample. The five-item FRAIL (Fatigue, Resistance, Ambulation, Illnesses and Loss of weight) assessment was used to measure frailty and categorise participants as frail (score of 3–5), prefrail (1–2) or robust (0).[40] Functioning in ADL and IADL was assessed using the Barthel Index[41] and Lawton and Brody's scale,[42] respectively. Self-reported presence or absence of eleven chronic diseases was recorded.

Statistical analysis

An exploratory factor analysis (EFA) was performed to identify the underlying factor structure of the IC construct using available data from our study population. Thirteen variables, SPPB, TUG, 5TSTS, GDS, EuroQol-5 Dimensions (EQ-5D) anxiety/depression, Memory, Executive, Orientation, Hearing, Vision, Exhaustion, MNA-SF and Grip strength, were included in the EFA based on empirical evidence[8 9] and their theoretical associations with the five IC domains. Seven of the variables, TUG, 5TSTS, GDS, EQ-5D anxiety/depression, Hearing, Vision and Exhaustion, were reverse-coded such that higher values represented better performance. Eigenvalues were used to identify the number of factors to retain and a cut-off of ≥0.4 factor loading was used to select the items to include in the model. The identified factor structure was further tested with confirmatory factor analysis (CFA). The CFA model was validated by assessing its fit with data using several goodness-of-fit indices: Root Mean Square Error of Approximation (RMSEA), Comparative Fit Index (CFI) and Tucker-Lewis Index (TLI). The criteria for good fit with data are RMSEA ≤0.8 and CFI and TLI values of ≥0.9.[43] Standardised factor scores for IC were calculated and applied in subsequent analyses.

Age was centred by subtracting all values by 65, such that 0 represents 65 years old and −10 represents 55 years old. The centred age variable was used in subsequent analyses. Simple linear regression was performed for each of the baseline demographic, economic and social characteristics with IC and LSM to identify potential confounders. Sequential regression analyses of LSM on IC were then performed: (1) the first model included LSM as dependent variable and IC as independent variable, (2) the second model was the first model with age, gender, education, housing, disposable income, employment, living alone, attendance in community/religious activities, having a confidant, contact with relatives/friends, helping others added as covariates and (3) the third model was the second model with addition of IC x age and IC x gender interactions. Chronic conditions were not included as covariates in our regression analyses as they are closely related to IC and separating their effects is not likely to be meaningful in answering the research questions posed in this study.

Standardised factor scores for the five subfactors were also calculated and applied in regression analyses to examine the association between the individual IC domains and LSM. All statistical analyses were performed using Stata/SE V.16.1 and R V.4.0.3.

RESULTS

Sample characteristics

Of 761 participants from the IPPT-S study, 751 were included in our analyses after removal of individuals with missing data in LSM. Age, gender and frailty status of the excluded participants were similar to the cohort included for analysis. Table 1 summarises the baseline sample characteristics. The mean age of participants was 67.6 (SD 7.03), with most participants being female (71.8%, N=539). 85.8% of participants were ethnically Chinese. Malays and Indians/other ethnicities constituted 9.72% and 4.53% of the participants respectively, which are slightly lower than in the 2020 national statistics (15% and 9.1%, respectively).[44] The mean total LSM score was 88.6 (SD 20.4) out of the maximum score of 120, with the lowest score being 16 and highest 120. 92.3% of the participants (N=693) attained a score of at least 60 and were regarded to have high participation, while the remaining 7.72% (N=58) have low participation with LSM score <60.

EFA, CFA and model fit

Summary statistics of the 13 variables used in the EFA are presented in table 2. The variables represented the five domains of IC: locomotion—SPPB, TUG, 5TSTS; psychological—GDS, EQ-5D anxiety/depression; cognition—Memory, Orientation, Executive; sensory—Hearing, Vision; vitality—Exhaustion, MNA-SF and Grip strength.

Table 3 shows the results of the EFA. The EFA suggested a five-factor model, with Eigenvalues ranging from 1.06646 to 2.62684. The five factors corresponded to the five IC domains, with items representing the domains locomotion, psychological, cognition, sensory and vitality loading onto factors 1–5, respectively. An exception lies in factor 2 in which there was cross-loading of *psychological* and vitality items—GDS and EQ-5D anxiety/depression (which are psychological measures) had factor loadings of 0.7881 and 0.7116, while Exhaustion and MNA-SF (which are vitality measures) had factor loadings of 0.4982 and 0.5563, respectively. However, in general, all items loaded well onto their respective factors, with factor loadings greater than or equal to 0.4 (range 0.4364–0.9049).

The EFA results were used to guide development of the CFA model. Variables Exhaustion and MNA-SF were mapped onto vitality domain despite the EFA findings due to consideration of their conceptual association with the IC vitality domain. Grip strength was removed from the model as an initial CFA iteration revealed poor factor loading of 0.105. The eventual CFA model was a second-order model with one general factor (IC) and five subfactors (locomotion, psychological, cognition, sensory and vitality) (figure 1). The model achieved good fit with data: χ^2 = 136.7 (df=49), RMSEA=0.049 (90% CI 0.039 to 0.059), CFI=0.954 and TLI=0.937. Ten of the 12 items had factor loadings greater than 0.4 (range 0.408–0.996). The remaining two items, Hearing and Memory, had factor loadings of 0.326 and 0.355, respectively, which are still in acceptable range. Of note, there is substantial variability in the loadings of the subfactors onto the general factor (IC), where cognition has the lowest factor loading of 0.155 while vitality has the highest factor loading of 0.979 among the five subfactors. This suggests that the five domains were not equally represented in the IC construct based on this model.

Associations between IC and LSM

Based on the second-order CFA model, standardised IC factor scores were calculated for each participant and used in subsequent regression analyses. IC was shown to have a statistically significant positive association with LSM (β=6.33; 95% CI=4.94 to 7.72; p<0.001) in a simple linear regression model (table 4). In other words, 1 SD increase in factor score for IC increases LSM by approximately six units. Given that three units of LSM represents the minimal clinically important difference (MCID) for LSM,[45] this effect is also clinically significant. Potential confounders were identified as variables that showed statistically significant (p<0.05) association with IC and LSM. Multiple linear regression analysis which included

Table 1 Summary of baseline sample characteristics

Variable	All Mean (SD) N=751*	Low participation (LSM <60) N=58	High participation (LSM ≥ 60) N=693
Demographics			
Age	67.6 (7.03)	70.6 (8.79)	67.3 (6.81)
Female gender (%)	539 (71.8)	43 (74.1)	496 (71.6)
Ethnicity (%)			
Chinese	644 (85.8)	45 (77.6)	599 (86.44)
Malay	73 (9.72)	9 (15.5)	64 (9.24)
Indian/others	34 (4.53)	4 (6.90)	30 (4.33)
Weight (kg)	60.2 (11.9)	61.9 (17.1)	60.1 (11.5)
Height (cm)	156.5 (8.01)	155 (7.77)	156.6 (8.02)
BMI	24.6 (4.57)	25.7 (6.86)	24.5 (4.35)
Social and lifestyle factors (%)			
Non-smoker	628 (83.9)	44 (75.9)	584 (84.5)
Teetotaller	539 (72.2)	39 (67.2)	500 (72.6)
Secondary/higher education	382 (51.1)	22 (37.9)	360 (52.3)
Living in two-room flat or larger	489 (65.4)	22 (37.9)	467 (67.7)
Active employment	236 (31.9)	3 (5.26)	233 (34.1)
Disposable income ('fair/more than enough')	563 (76.7)	32 (55.2)	531 (78.6)
Living alone	120 (16.0)	11 (19.3)	109 (15.8)
Attend religious/community activities	590 (79.4)	37 (66.1)	553 (80.5)
Have confidant	638 (85.3)	41 (71.9)	597 (86.4)
Frequent contact with friends/relatives (≥1 /week)	587 (79.4)	33 (58.9)	554 (81.1)
Help others	263 (35.3)	9 (16.1)	254 (36.8)
Functioning			
BI (max 20)	19.9 (0.52)	19.5 (1.10)	19.9 (0.429)
IADL (max 24)	22.2 (2.09)	19.5 (5.14)	22.4 (1.37)
Frailty (%)			
FRAIL questionnaire			
Robust (0)	584 (79.4)	22 (38.6)	562 (82.8)
Pre-frail (1–2)	143 (19.4)	28 (49.1)	115 (16.9)
Frail (3–5)	9 (1.22)	7 (12.3)	2 (0.29)
Medical conditions (%)			
Hypertension	361 (48.1)	33 (56.9)	328 (47.3)
Diabetes	154 (20.5)	16 (27.6)	138 (19.9)
Cancer (other than minor skin cancer)	36 (4.8)	2 (3.45)	34 (4.91)
Chronic lung disease	8 (1.07)	1 (1.72)	7 (1.01)
Heart attack	27 (3.60)	10 (17.2)	17 (2.46)
Congestive heart failure	11 (1.47)	2 (3.45)	9 (1.30)
Angina	17 (2.27)	4 (6.90)	13 (1.88)
Asthma	38 (5.07)	6 (10.3)	32 (4.62)
Arthritis	154 (20.56)	16 (27.6)	138 (20.0)
Stroke	36 (4.80)	8 (13.8)	28 (4.05)
Kidney disease	15 (2.00)	4 (6.90)	11 (1.59)

*Number of observations vary across variables due to missing data (N=734–751).
BI, Barthel Index; BMI, body mass index; FRAIL, fatigue, resistance, ambulation, illness and loss of weight; IADL, instrumental activities of daily living; LSM, life-space mobility.

Table 2 Descriptive statistics of measures of intrinsic capacity

IC domain	Variable	All Mean (SD) N=751*	Low participation (LSM <60) Mean (SD) N=58	High participation (LSM ≥60) Mean (SD) N=693
Locomotion	SPPB total score (max 12)	11.1 (1.62)	9 (3.27)	11.3 (1.31)
	TUG (s)	10.1 (3.81)	15.7 (8.75)	9.68 (2.73)
	Time taken for 5TSTS(s)	10.2 (4.16)	14.0 (7.63)	9.96 (3.68)
Psychological	GDS (max 15)	2.43 (2.62)	4.25 (3.34)	2.28 (2.50)
	<5 (no depression, %)	627 (85.0)	32 (57.1)	595 (87.2)
	EQ-5D anxiety/ depression (%)			
	'I am not anxious or depressed'	649 (87.7)	47 (83.9)	602 (88.0)
Cognition	CMMSE total score (max 28)	24.7 (2.84)	23.2 (4.05)	24.8 (2.70)
	≥21 (no cognitive impairment, %)	676 (91.9)	41 (77.4)	635 (93.0)
	Memory (max 6)	4.79 (1.00)	4.63 (1.03)	4.80 (1.00)
	Orientation (max 8)	7.72 (.786)	7.23 (1.43)	7.76 (0.696)
	Executive (max 7)	6.37 (.963)	6 (1.20)	6.40 (0.937)
Sensory	No hearing impairment (%)	606 (80.9)	41 (71.9)	565 (81.7)
	No visual impairment (%)	588 (78.5)	36 (63.2)	552 (79.8)
Vitality	Exhaustion - 'I felt that everything I did was an effort' (%)			
	Rarely or none of the time	643 (86.4)	41 (71.9)	602 (87.6)
	MNA-SF (max 14)	12.7 (1.60)	12.2 (2.11)	12.8 (1.55)
	12 (normal nutritional status, %)	598 (80.9)	36 (66.7)	562 (82.0)
	Grip strength (kg)	24.3 (6.91)	20.6 (6.41)	24.6 (6.87)
	Normal (≥18 kg in women and ≥26 kg in men, %)	586 (80.0)	27 (50.9)	559 (82.2)

*Number of observations vary across variables due to missing data (N=721–749).
CMMSE, Chinese Mini Mental State Examination; EQ5D, EuroQol-5 Dimensions; GDS, Geriatric Depression Scale; IC, intrinsic capacity; LSM, life-space mobility; MNA-SF, Mini Nutritional Assessment-Short Form; SPPB, Short Physical Performance Battery; 5 TSTS, 5 Times Sit-To-Stand; TUG, Timed Up and Go.

demographic (age, gender, education), economic (housing, disposable income, employment) and social variables (living alone, attendance in community/religious activities, having a confidant, contact with relatives/friends, helping others) revealed that IC remained independently associated with LSM (β=4.76; 95% CI=3.22 to 6.29; p<0.001). Thus, controlling for relevant demographic, economic and social factors, 1 SD increase in factor score for IC increases LSM by almost five units. This still represents a clinically significant effect. In the multiple linear regression model that included interaction terms IC x age and IC x gender, age and gender did not show significant modification on the effect of IC on LSM (β=0.082; 95% CI=–0.114 to 0.278; p=0.412 and β=–0.130; 95% CI=–2.97 to 2.71; p=0.928, respectively). Details of the above regression models are presented in online supplemental table 1.

Associations between IC domains and LSM

All five IC domains showed positive and significant association with LSM (β=4.76 to β=7.52), which remained significant even after controlling for confounders (β=2.55 to β=5.87; table 4). Among them, locomotion had the strongest association with LSM (β=7.52 before and β=5.87 after controlling for confounders). This means that 1 SD increase in locomotion factor score increases LSM score by 5.87 units after accounting for confounding factors, and this effect is clinically significant (β=5.87; >MCID of

Table 3 Exploratory factor analysis of intrinsic capacity items (N=751)

IC domain	Items	Factor 1	2	3	4	5
Locomotion	SPPB	**0.9018**	0.0160	0.0967	0.0034	0.0304
	TUG	**0.8462**	0.0352	0.1474	0.0280	0.0347
	5TSTS	**0.9049**	0.0347	0.0265	0.0288	0.0430
Psychological	GDS	0.1175	**0.7881**	0.0568	0.1538	−0.0775
	EQ-5D anxiety/depression	−0.0604	**0.7116**	−0.0393	−0.0412	0.0209
Cognition	Memory	0.0677	0.1373	**0.4571**	−0.0535	−0.5171
	Orientation	0.1356	0.0008	**0.7941**	0.0023	0.0068
	Executive	0.2728	−0.0252	**0.6374**	0.0402	0.0138
Sensory	Hearing	−0.0563	0.0693	0.1624	**0.7287**	0.2789
	Vision	0.1128	0.0954	−0.1270	**0.7608**	−0.2387
Vitality	Exhaustion	0.1954	**0.4982**	−0.2058	0.0698	−0.1601
	MNA-SF	−0.0632	**0.5563**	0.0835	0.0872	**0.4364**
	Grip strength	0.3251	−0.0120	0.0427	−0.0595	**0.6614**
	Eigenvalue	2.62684	1.72141	1.37600	1.15724	1.06646
	% of total variance	20.21	13.24	10.58	8.90	8.20
	Cumulative %					61.13

Extraction method: principal component factors. Rotation method: orthogonal varimax without Kaiser normalisation. Loadings larger than 0.40 are highlighted in bold.
EQ5D, EuroQol-5 Dimensions; GDS, Geriatric Depression Scale; IC, intrinsic capacity; MNA-SF, Mini Nutritional Assessment-Short Form; SPPB, Short Physical Performance Battery; 5TSTS, 5 Times Sit-To-Stand; TUG, Timed Up and Go.

three). On the other hand, cognition showed the weakest effect on LSM (β=4.76) and this was non-clinically significant after controlling for confounders (β=2.55; <MCID of three).

DISCUSSION

IC and LSM are two concepts that are of increasing interest in the field of population health. To our knowledge, this is the first study to consider the two concepts together and examine their association.

We demonstrated that IC has a positive and clinically significant effect on LSM, even after accounting for age, gender and other demographic and socioeconomic factors. This aligns with the ICF theoretical framework, which suggests that IC contributes to older adults' ability to participate in the community.[16] Our findings also corroborate with prior empirical evidence which demonstrated that older adults with frailty, a state of vulnerability to adverse health outcomes characterised by a decline in IC, have more restricted LSM compared with robust older adults.[46] Taken together, this suggests that intrinsic factors and physiological reserves of older adults have a role in determining how active they are in the community. However, notwithstanding the positive association between IC and LSM, it is important to consider that the ability of older adults to age well and correspondingly their life-space can be influenced by the physical environment serving as a barrier or facilitator and its interaction with IC.[47]

In addition, even in this cohort of relatively well and functionally independent older adults, as reflected by the overall high ADL and IADL scores, and only 1.2% being overtly frail, we have observed a significant positive association between IC and LSM. This further supports the concept of IC in monitoring overall health status of older people before they experience significant losses in functional ability and LSM.

Contrary to our initial hypothesis, our results showed that the magnitude of effect of IC on LSM does not vary according to age or gender. This suggests that effect of IC on LSM does not need to be considered in age-specific or gender-specific terms. The implication of this is that measures seeking to improve LSM by enhancing IC would apply to older adults across age and gender.

We also found that out of the five IC domains, locomotion has the strongest effect on LSM. This can be attributed to the fact that poorer physical performance and lower limb strength reduce one's ability to walk safely, which in turn deters a person from travelling long distances or going outdoors as frequently.[48] Although older adults are able to compensate for their physical deficits by using assistive devices or having personal assistance, their reliance on assistance implies that they have more limited autonomy over when and where they travel, which consequently results in more restricted LSM.[48]

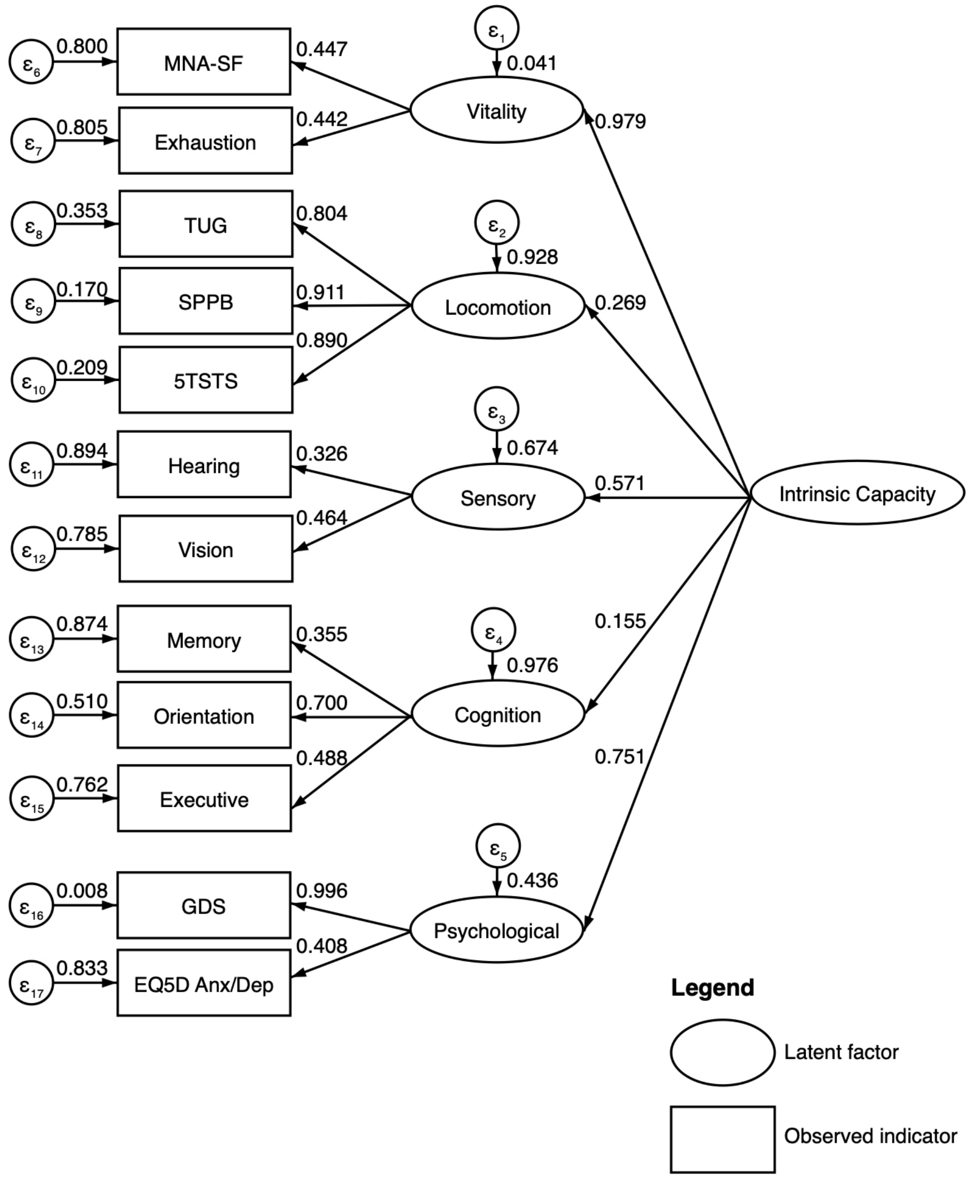

Figure 1 Second-order confirmatory factor analysis (CFA) model of intrinsic capacity. 5TSTS, 5 times Sit-To-Stand; EQ-5D Anx/Dep, EuroQol-5 dimensions Anxiety/Depression; GDS, Geriatric Depression Scale; MNA-SF, mini nutritional Assessment-Short form; SPPB, short physical performance battery; TUG, Timed Up And Go.

On the other hand, cognition was shown to have the weakest, although still statistically significant, association with LSM among the five domains. Unlike locomotion, there have been mixed reports regarding the relationship between cognitive function and life-space, with some studies demonstrating significant association of higher cognitive function with increased mobility,[18 49] and others reporting otherwise.[50 51] A larger life-space arguably connotes increased environmental complexity, and thus necessitates higher-order cognitive functions like planning, decision-making and judgement to successfully navigate through the environment.[49] However, having intact cognitive function may not necessarily translate into greater LSM. This has been attributed to the notion of self-induced dependence, where older persons behave in accordance with others' expectations of them instead of performing at their true ability level.[49 52] Many negative stereotypes of ageing about the elderly continue to prevail in many societies, for instance, the perception of cognitive impairment and 'senility' as an inevitable consequence of ageing. As a result, such societal impressions may insidiously affect older adults' perceptions of their own abilities and cause them to limit their mobility below what they are capable of achieving.

The weak association of cognition with LSM could also be due to the fact that CMMSE has a ceiling effect on individuals with higher educational attainment, whereby highly functioning individuals with very early cognitive impairment may still perform within the normal range, that is, scoring ≥21 out of 28.[53] However, there is a lack of more granular psychometric measures of cognition to circumvent this problem.

Table 4 Regression analyses of intrinsic capacity and its domains on LSM

	Model			
	1		2	
Predictor	β (SE)	95% CI	β (SE)	95% CI
IC	6.33 (0.708)*	(4.94 to 7.72)	4.76 (0.782)*	(3.22 to 6.29)
Locomotion	7.52 (0.692)*	(6.17 to 8.88)	5.87 (0.769)*	(4.36 to 7.38)
Psychological	4.98 (0.722)*	(3.56 to 6.39)	3.50 (0.780)*	(1.97 to 5.03)
Cognition	4.76 (0.724)*	(3.34 to 6.18)	2.55 (0.739)*	(1.10 to 4.01)
Sensory	5.69 (0.715)*	(4.29 to 7.09)	3.70 (0.750)*	(2.23 to 5.17)
Vitality	6.29 (0.708)*	(4.90 to 7.68)	4.74 (0.781)*	(3.20 to 6.27)

Model 1: Univariate regression model with LSM as the outcome variable; Model 2: Multivariable regression model with LSM as the outcome variable and demographic (age, gender, education), economic (housing, disposable income, employment) and social (living alone, attendance in community/religious activities, having a confidant, contact with relatives/friends and helping others) variables added as covariates.
*P≤0.001.
IC, intrinsic capacity; LSM, life-space mobility.

Strengths and limitations of study

This study demonstrated that multiple observable and measurable variables can be aggregated into a composite IC score using factor analysis. Given that there is currently no standardised tool/instrument for the quantitative measure of IC, this study thus contributes to the growing literature that supports the use of this construct in the assessment of older adults and also aids in the development of tools/instruments that enable the clinical application of IC.

Furthermore, our results suggest that IC is a potential target for interventions that aim to enhance LSM and promote healthy ageing in older adults. Such interventions are likely to adopt a more functions-based and proactive approach by engaging and empowering seniors to be involved in improving their own health. Interventions are also likely to be more personalised and tailored to individual needs, priorities and values. Moreover, while interventions targeting IC and those addressing environmental factors such as building infrastructure or social support are clearly complementary in enhancing participation, the former may be less costly to implement.

The study also has limitations to be acknowledged. Given that the analyses were cross-sectional by design, causal inferences and directionality could not be determined. As such, the associations should be examined further using longitudinal data. A recent study on longitudinal ageing profiling identified a set of biomarkers including proteins, cytokines and clinical laboratory values, as well as subjective measures like physical activity and dietary habits, which trajectories can be monitored over time to provide insight into individuals' ageing patterns.[54] Future studies involving the longitudinal measurement of IC could thus potentially adopt these measures. A second limitation is that the study sample consisted of relatively high functioning older adults. Moreover, individuals with mobility limitations (inability to ambulate at least 4 m independently) were excluded. As a result, the associations of IC and its domains with LSM in this study may be underestimated. This also limits the generalisability of our results to other populations. Lastly, the use of self-reporting instrument UAB-LSA to assess LSM may result in subjective and inaccurate measurements due to recall bias, particularly in older adults with cognitive impairment. However, the UAB-LSA instrument has been shown to correlate well with objective data from tracking devices.[55] In addition, the sensory domain was measured using self-reported questionnaire with binary yes/no questions without delineation of the severity of impairment. Objective measures of visual acuity and audiometry could have been adopted for more accurate assessments.

CONCLUSION

In conclusion, this study demonstrates that IC has a positive effect on LSM which is statistically and clinically significant. Age and gender do not significantly modify the relationship between IC and LSM. These findings provide valuable information for healthcare providers who aim to enhance LSM and promote healthy ageing in older adults.

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Contributors JQL, YYD and YSN conceived of the research and were involved in the conceptualisation and design of the study. JQL undertook the analyses and was responsible for the final drafting of the paper. YYD oversaw the analyses and contributed to the drafting of the paper. YSN and LT are principal investigators of the IPPT-S study from which data were used. AL was involved in data acquisition and management. All authors reviewed the accuracy and integrity of the work. YSN is the guarantor of the work and is responsible for the overall content.

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